Int.J.Curr.Res.Aca.Rev.2023; 11(7): 9-17

International Journal of Current Research and Academic Review

ISSN: 2347-3215 (Online) Volume 11 Number 7 (July-2023)

Journal homepage: http://www.ijcrar.com

doi: https://doi.org/10.20546/ijcrar.2023.1107.002

Deficit Irrigation as a Method to Increase Water Use Efficiency of Some Crops Produced in Ethiopia: A Review

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Abstract

Deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. In Ethiopia crop like maize, common bean, soybean, potato, wheat and onion were affected by severe moisture stress. In areas where water is the most limiting resource to production, maximizing water use efficiency may be more profitable to the farmer than maximizing crop yield. This is because the water saved when deficit irrigation is applied becomes available to irrigate more land.

Article Info

Received: 11 May 2023
Accepted:25 June 2023
Available Online: 20 July 2023

Keywords

Deficit irrigation, water use efficiency, growth stage.

Introduction

Irrigation improves crop production and productivity by contributing towards food security, self-sufficiency and export market. Thus, irrigation water is one of the important factors for crop production provided that other essential requirements like nutrient, climate and soil environment are sufficient. Nowadays, the government of Ethiopia is giving more emphasis to the sub-sector by way of enhancing the food security situation in the country. Efforts are being made to involve farmers progressively in various aspects of management of small-scale irrigation systems, starting from planning, implementation and management aspects, particularly, in water distribution, operation and maintenance to improve the performance of irrigated agriculture. As a result, irrigation infrastructures are increasing year after year, which show nationwide positive development implications and experiences in small and large scale irrigation schemes. The expansion of irrigated agriculture to feed the ever-increasing population on one hand and the increasing competition for water due to the development of other water use sectors on the other hand, as well as increasing concerns for environment, necessitated the improvement of water productivity in irrigated agriculture to ensure sustained production and conservation of this limited resource (Awulachew *et al.*, 2007).

Water is the major yield limiting factor in agricultural system. In the present era of climate change and colossal population pressure, drought is becoming a critical problem, thus making the water a sparse resource in the world (Anwar *et al.*, 2011). The sustainable use of water in agriculture has become a big concern. The adoption of strategies for saving irrigation water and maintaining acceptable yields may contribute to the preservation of this ever more restricted resource (Topçu *et al.*, 2007).

This long-term use of water in irrigated agricultural systems, with an emphasis on reducing water use, requires careful planning and management.

Advantages of deficit irrigation in arid and semi-arid areas of Ethiopia

Deficit is one of the irrigation management practices which could result in irrigation water saving (Barker *et al.,* 1999). It is a water-saving strategy under which crops are exposed to a certain level of water stress either during a particular developmental stage or throughout the whole growing season (Pereira *et al.,* 2002). Deficit irrigation is strategies allow crops to sustain some degree of water deficit and with insignificant yield reduction. The classic deficit irrigation strategy (DI) implies that water is supplied at levels below full evapotranspiration (ETc) at some growth stages or throughout the growing season. The other two main deficit irrigation strategies based on the physiological knowledge of crops response to water stress, are regulated deficit irrigation and partial root zone drying (Costa *et al.*, 2007). In the past, crop irrigation requirements did not consider limitations of the available water supplies. Therefore practice of new irrigation technologies such as deficit irrigation is one of the water management strategies to conserve water resources in addition to increasing water use efficiency in agriculture (Horst *et al.,* 2005). This approach to the management of water has been reported to increase yields in a number of crops such as beans and other legume crops (Bonane *et al.,* 2019). In semi-arid regions of Ethiopia, irrigation was affected by water scarcity. Moreover in Ethiopia, there is spatial and temporal variability of rainfall to meet the timely required amount of water application for plant growth except in some highland areas (Admasu *et al.*, 2019). In arid and semi-arid of Ethiopia, moisture stress is a frequently occurring phenomenon which is climate related natural hazard minimizing agricultural production in the country from time to time. In low land areas where moisture stress is common in crop production, drought leads to major socioeconomic problems like food insecurity, poverty and low quality of life.

Therefore, there must be appropriate technologies for enhancing the socioeconomic condition of farming community with locally available resources. In arid and semi-arid areas where moisture stress is the main challenge for crop production, the spatial and temporal variations intensify the problem. Moreover, design of irrigation schemes does not address the situation of moisture availability for crop and the competition between different sectors. For improving water use efficiency, there is a growing interest in decreasing irrigation water amount, where by water supply is minimized, and stress is allowed with minimal effects on crop growth. Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains by maximizing Water use efficiency.

Benefit of increasing water use efficiency under deficit irrigation

Improving water use efficiency in agricultural sector was used for sustainability of irrigated agriculture, Improvement of the environment and Ensuring food security (Rosenzweig and Parry, 1994; González, 2010). Deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought-tolerant phonological stages, often the vegetative stages and the late ripening period.

Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle. By limiting water applications to drought-sensitive growth stages, this practice aims to maximize water productivity and to stabilize - rather than maximize – yields (Geerts and Raes, 2009). In areas where water is the most limiting resource to production, maximizing water use efficiency may be more profitable to the farmer than maximizing crop yield. This is because the water saved when deficit irrigation is applied becomes available to irrigate more land. In the arid region, irrigation is the dominant factor influencing agricultural production (Oweis *et al.*, 2003).

Effect of deficit irrigation of some crop produced in Ethiopia

Maize (*Zea mays* L.)

Severe water stress affects maize grain yield during tasseling, silking and early grain-filling stages. Hence other agricultural inputs need to be appropriately used to enhance productivity by maintaining improved water use efficiency since WUE has increased with decreasing water application which, however is also related to decreased grain yield (Ayana, 2011).

Different authors (Yenesew and Tilahun, 2009; Gebreigziabher, 2020; Kefale and Ranamukhaarachchi,

2004) revealed that the maximum yield of maize was obtained when the entire crop water requirement is fulfilled, practicing deficit irrigation could increase the irrigated area as a result of high water use efficiency. Therefore, deficit irrigation technique is much important where a limited amount of water is available for irrigation and irrigation water management is very poor.

Wheat (*Triticum aestivum* L.)

There is spatial and temporal competition for both quality and quantity of water due to human activities like population growth, urbanization, increased living standards, growing competition for water, and pollution. “Wheat is one of the major food security crops in Ethiopia but its productivity is reduced due to water scarcity, especially during the off season.

Addressing these problems might be essential to increase water use efficiency” (Asmamaw *et al.,* 2023). Practicing deficit irrigation used to improve water use efficiency with insignificant wheat grain yield reduction that leads to save irrigation water volume under moisture stressed condition (Meskelu *et al.,* 2017; Tawakoni and Moghadam, 2012).

Common bean (*Phaseolus vulgaris* L.)

Common bean crop is an important commodity in the cropping systems of smallholder farmers for food and income generation in drought-prone areas of Ethiopia (Pereira, 2017). Extreme water deficit can affects agricultural production particularly, short season growing grain legume crops such as common bean.

Different author’s described that, moderate to high drought stress can reduce biomass, number of pods and seed, days to maturity, harvest index, seed yield and seed weight in common bean (Acosta-Gallegos and Adams, 1991; Ramirez-Vallejo and Kelly, 1998). (k.ghassemi-golazani, 2008) reports that percentage of ground cover and number of grain per plants are the most important traits for estimating yield potential of common bean cultivars under both well and limited irrigation conditions. Heshmat *et al.,* (2021) reports that leaf area index (LAI), relative leaf water content (RLWC) and grain yield decrease with increasing water stress. **(**Addisu, 2022) reported that, practicing of deficit irrigation leads to increment of area irrigated with the water saved to compensate for the yield loss by improving water productivity of common bean crop.

Soybean (*Glycine max* L.)

Soybean is one of the essential food crops of the world and is becoming an important industrial and multipurpose crop. In Ethiopia, soybean is a multipurpose most nutritionally rich crop as its dry seed contains the highest protein and oil content (Hagos and Bekele, 2018). Precise knowledge of soybean response to water stress and investigation of drought tolerance varies by growth stage, cultivars needs to be conducted (Abeba, 2021). According to Karam *et al.,* (2005) 65% of soybean evapotranspiration occurred during the seed filling period and showed a major sensitivity to moisture stress during this period.

Potato (*Solanum tuberosum* L.)

Potato crop is one of the most essential crops in the world are frequently served whole or mashed as a cooked vegetable (Fabeiro *et al.,* 2001). Potato is very sensitive to water stress and tuber yield may be considerably reduced by soil water deficits due to its sparse and shallow root system (Porter *et al.,* 1999).

Therefore, irrigation is always needed for production of high yielding crops (Fabeiro *et al.,* 2001). However, the increasing worldwide shortage of water resources requires optimization of irrigation management in order to improve water use efficiency (WUE). Increase the efficiency of use of the water that is available is an important for higher yields per unit of irrigation water applied.

Onion (*Allium cepa* L.)

Among horticultural crop onion is one of the most highly consumed than other vegetable crops in Ethiopia (Bossie *et al.,* 2009; Assefa *et al.,* 2016). According to Bekele and Tilahu (2007) “when water deficit is imposed early in the growing season, maximum yields of onion could easily be sustained provided adequate watering conditions take place during the rest of the growing season”. Further the authors concluded that, Critical period for onion irrigation is the bulb formation growth stage. This period coincides with the highest irrigation requirement and the crop cannot withstand water stress without substantial reduction on yield. On the other hand (Dirirsa *et al.,* 2017) described that higher water productivity can be obtained by stressing onion crop by one-quarter deficit at developmental and/ or bulb formation stage than stressing by one-half.

Table.1 Potato growing farmers and sample size

Districts	Kebeles	Total house holds	Sample size (Formula, 2)	Percent
Degem	AnoDegem	729	11	8.46
	Anokere	675	11	8.46
	TumanoAbdi	1316	20	15.38
	ElamuEferso	688	11	8.46
G/Jarso	G/Gabar	1504	23	17.69
	AnoBonaya	1316	20	15.39
D/Libanos	Tumano	410	7	5.39
	Wakene	995	15	11.54
	G/Wortu	745	12	9.23
Sum of house holds		8378	130	100

Source: Degem, G/Jarso and D/Libanos District Agricultural office, 2014/2015

Table.2 Demographic characteristic of sample households

Variables		Frequency			Percent
Gender of HH head					
Male		111			85.38
Female		19			14.62
Age of HH head					
15-65 years old		123			94.62
>65 years old		7			5.38
Education level of HH head					
No education		9			6.9
Basic education		38			29.2
Primary school		63			48.5
Secondary school		17			13.1
Above secondary school		3			2.3
Family size of HH	**Frequency**	**Percent**	**Mean±SD**	**Minimum**	**Maximum**
Degem	54	41.54	6.34±2.39	2	14
G/Jarso	43	33.08	5.66±2.02	1	9
D/Libanose	33	25.38	5.82±2.04	1	10
Total	130	100	5.94±2.15	1	14

Source: Own field survey data, 2023

Table.3 Land holding and Potato production experience

Variables	Frequency	Percent	Mean ± SD	Minimum	Maximum
Potato Farm experience of HH (Year)					
Degem	54	41.54	8.27±5.6	1	30
G/Jarso	43	33.08	9.26±4.96	3	20
D/Libanos	33	25.38	8.24±4.23	2	28
Total	130	100	8.59± 4.93	1	30
Total land size of HH (in ha)					
	0-1	>1			
Degem	25	29	1.6 ± 1.19	0	5
G/Jarso	31	12	1.12 ± 0.91	0.25	4
D/Libanos	10	23	2.58 ± 1.56	0	5
Total	66	64	1.76 ± 1.22	0	5

Source: Own field survey data, 2023

Table.4 Potato farming practices in research area

Variables	Frequency	Frequency	Percent
Planting materials	Improved Variety	87	66.9
	Not known	43	33.1
	Total	130	100
Seed tuber size	Large	18	13.8
	Medium	93	71.5
	Small	19	14.6
	Total	130	100
Inflorescence remove	Yes	41	31.5
	No	89	68.5
	Total	130	100
Fertilize use	Yes	87	66.93
	No	43	33.07
	Total	130	100
Disease control	Yes	56	43.1
	No	74	56.9
	Total	130	100

Source: Own field survey Data, 2023

Table.5 Productivity and production status of potato

Variable	Frequency	Percent
Productivity (ton ha^{-1})		
<13.279	98	75.4
>13.279	32	24.6
Total	130	100
Potato Production status		
Increase	44	33.8
Decrease	86	66.2
Total	130	100.0
Awareness on potato production system		
Yes	18	13.8
No	112	86.2
Total	130	100.0
Hedgehog effect		
Yes	77	59.23
No	53	40.77
Total	130	100.00

Source: Own field survey Data, 2023

Table.6 The major potato production constraint

	Priority ranking									
	1st	**2nd**	**3rd**	**4rth**	**5th**	**6th**	**7th**	**8th**	**Index**	**Rank**
Disease prevalence	35.00	25.00	12.00	14.00	6.00	5.00	0.00	0.00	0.21	2.00
Insufficient high-quality seed	43.00	35.00	15.00	11.00	7.00	1.00	0.00	0.00	0.25	1.00
Poor soil fertility	1.00	6.00	12.00	5.00	6.00	2.00	1.00	0.00	0.06	8.00
lack of fertilizer	2.00	9.00	13.00	20.00	9.00	5.00	0.00	0.00	0.17	4.00
lack of inflorescence removal	12.00	40.00	16.00	11.00	3.00	2.00	0.00	0.00	0.18	3.00
Variability of climate	0.00	0.00	2.00	5.00	2.00	3.00	0.00	0.00	0.02	10.00
Shortage of water	6.00	7.00	10.00	4.00	7.00	4.00	3.00	0.00	0.07	7.00
size of tuber	0.00	0.00	1.00	3.00	2.00	0.00	0.00	0.00	0.01	11.00
Lack of awareness on potato production system	3.00	12.00	15.00	20.00	29.00	10.00	7.00	0.00	0.15	5.00
poor drainage	3.00	5.00	10.00	5.00	3.00	1.00	0.00	0.00	0.05	9.00
Traditional irrigation	0.00	0.00	0.00	1.00	6.00	2.00	0.00	0.00	0.00	12.00
Hedgehog attacks	14.00	2.00	10.00	8.00	12.00	13.00	7.00	1.00	0.11	6.00
Total	119.0	141.0	116.0	107.0	92.0	48.0	18.0	1.00		

Source: Own field survey data, 2023

Table.7 Determinant of potato production (OLS estimates)

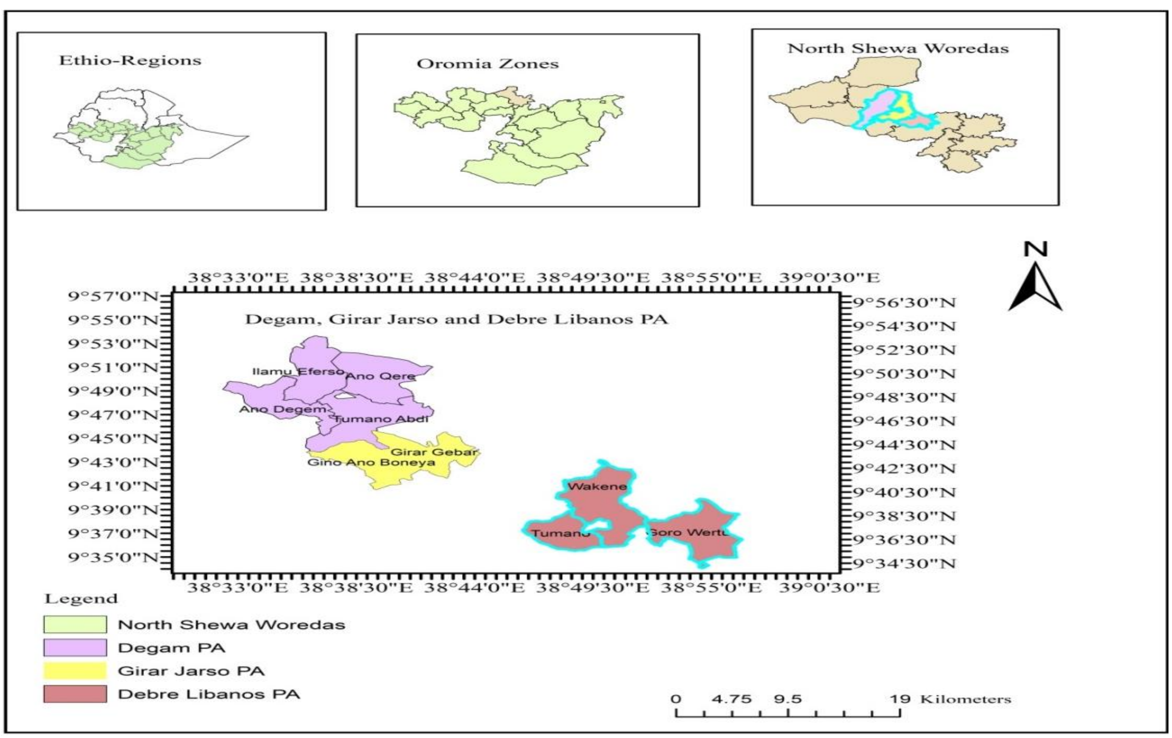
Variables	Regression coefficients	Std. Error	t-value	Sig.
Family size	0.047	0.027	1.727*	0.087
Tuber size	0.366	0.113	1.35***	0.002
Inflorescence remove	0.889	0.038	3.632***	0.000
Land hold size	-0.04	0.118	1.664*	0.099
Education level	0.266	0.051	4.903***	0.000
Production experience	0.049	0.011	4.907****	0.000
R^2	0.093			
F-value	2.093			

*** and * implies statistically significant at 0.1% and 5% level respectively Source: Own field survey Data, 2023

Appendix.1 Multicollinearity test

Variables	VIF	Tolerance (1/VIF)
HH-Age	2.506	0.399
Family size	1.649	0.606
Education level	1.542	0.649
Land Hold size	2.533	0.395
Production Experience	2.330	0.429
planting materials	1.520	0.658
Tuber size	1.295	0.772
Pest control	1.055	0.948
Inflorescence Remove	1.121	0.892

Fig.1 Map of the study area for survey.



Deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. Deficit irrigation techniques can be applied to several crops, like maize, common bean, soybean, potato, wheat and onion particularly in arid and semi-arid area in order to improve water use efficiency and save water. Better understanding on the vulnerability of each developmental phase of plants to water deficits as well as drought tolerance mechanism of crops are also important in order to set the most appropriate deficit irrigation level for each crops.

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How to cite this article:

Addisu Asefa Zelalem Tamiru. 2023. Deficit Irrigation as a Method to Increase Water Use Efficiency of Some Crops Produced in Ethiopia: A Review. *Int.J.Curr.Res.Aca.Rev.* 11(07), 9-17.
doi: https://doi.org/10.20546/ijcrar.2023.1107.002